THE TEXAS SOLAR D HOUSE

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ABSTRACT

The Solar Decathlon provided a national forum for competition among fourteen university student teams, each of which designed, built, and operated a totally solar-powered home with a home office and their transportation needs using a solar-charged vehicle. The competition took place on the National Mall in Washington D.C., where each house was constructed and operated from September 18 to October 10, 2002. The competition consisted of ten contests focusing on energy production, energy-efficiency, design, thermal comfort, refrigeration, lighting, communication and transportation

Professor Michael Garrison of the School of Architecture directed the University of Texas at Austin (UT) Solar Decathlon team along with Pliny Fisk, co-director of the non-profit Center for Maximum Potential Building Systems in Austin, Texas. The graduate student team developed a design that features an open building system using a reusable kit of parts that sits lightly on the land and forms the superstructure around a mobile utility environment. Our investigations suggest that progressive technologies offer solutions to the serious emerging challenges of energy efficiency and sustainable development and thereby become a strong design shaping force. These progressive technologies: photovoltaic (PV) power, passive solar heating, daylighting, natural ventilation, and solar hot water heating were integrated with concepts of affordability and energy conservation to help promote an ideology of sustainable architecture.

1. DESIGN

Given the fact that the competition brief implied a portable and temporary structure that could be erected in a few days without the use of heavy cranes, the UT Solar Decathlon House is built for change. Gone are nails and glues, cast in place concrete footings and structural welds. In their place are screws, pre-cast foundation pads and structural bolts. The major difference between these scenarios is in the connections between parts; the UT House can come apart and adapt without the destruction of materials.

The UT Solar Decathlon House separates the layers of utilities, structure and infill walls. The entanglement of utilities normally hidden behind gypsum board walls is replaced with utility runs that are in the structural columns and beams and can be accessed easily without disruption to the walls. Likewise the disentanglement of utilities from walls enables controls and utility lines of all types to evolve with technology enhancement.

1.1 Mobile Utility Environment

Our team modified a standard Airstream trailer to meet the plumbing (kitchen, bathroom and laundry) needs of the competition. The team "gutted" the Airstream down to the frame and several layers of Icynene insulation were installed so that a better buffer against the exterior climate was established. The interior was finished with bamboo flooring and recycled aluminum wall and ceiling panels. New interior cabinetry was added to house the Airstream's energy and water efficient appliances including a specially made energy-efficient Sunfrost-D.C. refrigerator, an Equator dishwasher that uses only 4.75 gallons (18 liters) per cycle, an Equator combination washer- dryer that uses only 8.27 gallons (31.3 liters) per cycle, a CookTek induction cook top, a General Electric flash-bake oven and a Sun Oven solar cooker for the outside grill. An integral bamboo table and bench were constructed to serve as the dining room and energy efficient lighting was added that consumes less than .5 watts per square foot (joule/sec per .092 square meters). The UT Solar Decathlon Airstream receives all of its power through a series of photovoltaic (PV) arrays.

Fig. 1. Airstream functions as a mobile utility environment.

The creative integration of an Airstream trailer into our scheme has the added benefit of isolating all the heat and humidity producing equipment from the rest of the house enabling the rest of the house to have lower internal gains.

2. ENVIRONMENTAL CONTROLS

In order to make the solar decathlon project work effectively with the sun as its sole power source we employed energy conservation techniques including using, caulking, R-30 wall and Roof Structural Insulated Panels, and double-pane Low-E, Argon filled windows and doors. Secondly, we integrated into the Design energy efficient environmental controls strategies divided into five systems:

* Natural and solar induced ventilation
* Passive solar gain and/or shading
* Daylighting
* Solar hot water heating and Hydro- Air Mechanical Heating and Cooling
* Photovoltaic power

The first three systems are passive, meaning that no electricity or mechanical parts are involved. The last two are active, since they involve the pumping of water and electrical generation via of PV cells.

2.1 Ventilation

In order to reduce the dependency on active cooling, natural ventilation was designed as the primary means of cooling for much of the year. Since the building relies solely on solar power to supply all its needs, designing for ventilation allows the active cooling loads to be reduced. Back up cooling loads are provided by small Hydro-Air hydronic fan coil units coupled with an ice-battery (thermal storage) unit.

The project goal was to channel prevailing breezes into the building, increase their velocity so as to maximize the cooling effect, and to ensure that all of the inhabited volume of the spaces had effective air movement.

The solar decathlon house is based on the principles of a historical dog run house scheme that emphasizes natural ventilation cooling and was designed to be a demonstration of natural ventilation and other "green building " techniques for an energy-efficient and comfortable home.

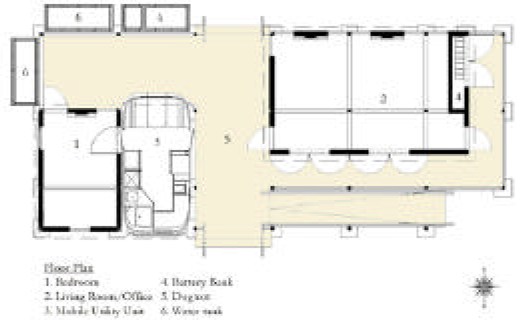

Fig. 2. UT Solar Decathlon House Plan, based on a dog run (5) scheme to maximize natural ventilation.

The house is a rectilinear configuration, with the dog run corridor bisecting the plan running from south to north. The living spaces are arranged on both sides of this corridor, with door openings onto the corridor and window openings out of the sides and north wall of the house. The plan is staggered to provide opportunities for creating pleasant outdoor rooms that take advantage of the breezes. When a summer breeze sweeps through the central corridor, it creates a low-pressure zone along its path. Simultaneously, the breezes striking the front and sidewalls of the house, finding only small windows to penetrate, create high-pressure zones. The combination of these two pressure conditions, in turn forces an accelerated airflow through the openings in the front and sidewalls of the house. The window openings can be controlled to modulate the velocity and channel the direction of the airflow

Because summer breezes in Washington D.C. are most active in the morning and late afternoon the dog run porch is used during these periods for immediate cooling ventilation and for "loading" the house with morning coolness that is retained in walls, floors and furniture. Conversely, the evening breezes are used to "flush" the house of heat that accumulates during the afternoon.

The volume of air that flows through a structure is governed by the size of the window openings. The velocity of air movement through the structure is maximized, creating the greatest cooling, when the area of outlets is greater than the area of inlet openings. The hopper windows used in the building were designed to increase effective ventilation through the building by causing added disturbance to the flow of air. The deflecting ability of the windows employed on the south facing windows of the solar decathlon home are used to direct air streams, which normally flow, along the ceiling to move down into the living zone.

The careful sizing and placement of air inlets and outlets greatly enhanced the cooling effect of cross ventilation. The window outlet air for the solar decathlon house is two times the inlet area. CFD simulations determined than an 8 mile per hour (1.6 kilometers per hour) breeze could achieve up to 50 air changes per hour moving at a speed of 566 (fpm) feet per minute (172.5 meters per minute). Air moving at 566 fpm will increase the upper temperature range of the house interior bioclimatic comfort zone.

Once the window schemes were worked out, the team built a physical 3/4 inch (1.9 centimeters) scale model and tested it at the University of Texas Pickle Research Center wind tunnel facility. The wind tunnel test confirmed that a 2 to 1 north south ratio of windows worked if the north openings were spread out. High north wall vents were effective, the dog run was the breeziest part of the house and openings in the east and west walls are essential when the breeze is along an E-W axis.

During the heat of the day a ventilated air space with a PV roof over a radiant barrier shields the ceiling from intense solar radiation. Continuous soffit vents at the eves of the roof overhang vent the attic. The air is exhausted at the peak of the roof using a continuous metal ridge vent. The reflective roof, a radiant roof barrier, a ventilated air buffer and R-30 Structural Insulated Roof Panels keep the mean radiant temperature of the ceiling cooler. The broad roof overhangs; a radiant wall barrier, light exterior colors, and R- 30 Structural Insulated Wall Panels also keep the mean radiant temperature of the walls cooler. The cooler mean radiant surface temperatures and the use of ceiling fans extend the upper limit of comfort zone and minimize the need for additional active, or mechanical cooling.

2.2 Passive Solar Heating

Although the Solar Decathlon competition ran from late September to early October 2002 in Washington D.C., which had generally mild weather at that time, the project was designed for high performance during cold winter months and hot summer periods in Austin, Texas where it makes its home. The goal was to use direct gain to trap solar radiation during the winter days and to have a highly insulative thermal envelope that prevents this heat from escaping during the night in order to reduce the reliance on active mechanical heating.

Fig. 3: Passive Solar Heating through south facing windows.

Based on Visual DOE-3 simulations passive solar heating was found to be adequate in maintaining comfortable conditions in winter inside the house. An optimum balance point between maximizing heat gain and minimizing afternoon overheating was achieved with a south-facing glazing ratio of 1.2 square feet of glazing per square foot of conditioned floor area. This glazing ratio is calculated to provide up to 72% of the solar heating fraction while minimizing the diurnal temperature swing. A back-up heating system that uses hot water supplied to small fan-coil units is designed to provide the make-up heating required for cool morning periods in Washington D.C. and in Austin, Texas.

2.3 Daylighting

To reduce the need for artificial lighting and therefore reduce the demand for solar power, natural daylight was the primary source of lighting. Daylighting reduces the need for excessive amounts of electrical lighting required to illuminate the space. However, too much daylighting may produce glare and an unacceptable amount of heat gain.

Fig. 4: Daylighting of the solar decathlon interior

Good daylighting is achieved in the dogtrot design by providing bilateral lighting, (light from two sides). A deep roof overhang along the south elevation controls glare

Using the rectilinear daylight simulator at The University of Texas at Austin, we were able to test the light intensity in various locations within our 3/4” = 1’ scale model. Light sensors were affixed at a height of 30” (scaled) above the floor. Using the daylight fraction method, we were able to convert values into footcandles specifically for a typical overcast Washington D.C. sky.

We found that it was not difficult to achieve the minimum intensity (15 footcandles) of uniform light at the work plane throughout the building during the middle of the day. Furthermore, with the narrow plan (13.5’ deep), the daylighting was relatively balanced.

2.4 Solar Water Heating

The solar decathlon project employs an evacuated solar water system manufactured by Thermo

Technologies to reduce the need for electric solar water heating. The direct pump system uses an electric circulating pump to move heat from the 30-tube manifold evacuated tube solar collector to a 90-gallon water storage tank.

Fig. 5 Evacuated tube solar hot water collectors

A differential controller turns the circulating pump on or off as required. There are two sensors, one at the outlet of the collectors, and the other at the bottom of the tank. They signal the controller to turn the pump on when the collector outlet is 20°F warmer than the bottom of the tank. It shuts off when the temperature differential is reduced to 5°F. The philosophy behind this design is that the cost of heating your collectors with hot water from you tank is low cost freeze protection if only required occasionally. These systems are commonly used in the Sunbelt, and only where freezing is a rare occasion. The annual total BTU's collected per square meter (10 tubes) equals 3,602,086 for Washington D.C., and the annual total BTU's collected per square meter for Austin, Texas equals 4,625,681. Beyond domestic hot water use the hot water in the tank was used in conjunction with a Hydro-Air hydronic fan-coil unit to provide back up heating during extreme conditions.

2.5 Photovoltaic (PV) power system

To meet the power needs of the solar decathlon's modern home-office, a stand-alone solar photovoltaic power system forms an integral part of the design. A stand-alone system has to have a battery bank that services a certain number of dark days, which in our case was designed for 3 dark days. This does not imply that the battery bank will discharge entirely if there are three moderately cloudy days. PV modules continue to produce power from natural ambient light during cloudy days, although at greatly reduced efficiency, and so the batteries received some charge during cloudy periods during the competition and power in the batteries was not a real problem even during several days of cloudy weather.

The 3.6 kW PV collector array, which covers a portion of the roof area above both the bedroom and living room sections of the house, supplies power that is routed through Schottky diodes, lighting arrestors and charge controllers to a battery bank. The PV arrays were mounted at an incline angle of 20 degrees to the horizontal and face due south.

Fig. 6: Solar PV system-25 BP solar PV panels and 6 ASE PV panels on the solar decathlon house in Austin, Texas

All the electric loads in the home are supplied from the battery bank. This ensures that each load receives a steady power supply irrespective of weather conditions and time of day. Power from the batteries flows through a Trace SW5548OG Inverter that coverts the DC input into a sine wave AC output to service all the loads in the house except the refrigerator. The power then flows to an AC panel-board that consists of breakers for each circuit and one main circuit breaker (MCB). The office, Airstream, solar car, and the bedroom are each on separate circuits. The refrigerator is on a DC circuit.

2.5.1 Load Analysis

The PV power system was sized after a detailed load analysis. The type of current drawn by each load, its power consumption and the number of estimated hours of daily use were tabulated. This information allowed us to calculate the average total energy (Watt-Hrs) that would be needed to run the house each day. Solar radiation data for Washington, D.C. and Austin, Texas, along with the specifications of PV module types were used in conjunction with the load analysis to estimate the number of PV modules needed. Our calculations projected the need for 25- BP solar 275 PV modules that use mono-crystalline silicon technology and 6-ASE-300 PV modules that use multi-crystalline silicon technology. Table 1 shows how much power could be generated per day by the PV array, which ranges from a minimum of 10.33 KWh in January to 21.2 kWh in June.

MONTH	Sun hrs/day	Total Power (Wh)
		25 BP+6 ASE
Jan.	2.81	10326.75
Feb.	3.85	14148.75
Mar.	4.69	17235.75
Apri.	5.61	20616.75
May	5.58	20506.50
Jun.	5.78	21241.50

July	5.75	21131.25
Aug.	5.53	20322.75
Sept.	4.8	17640.00
Oct.	4.29	15765.75
Nov.	3.69	13560.75
Dec.	2.79	10253.25
Yearly		**202749.75**

Table 1: PV Output

Retail costs quoted by PV panel suppliers were in the range of $10,000 a kW, thus a 3.6 KW system would retail for $36,00 and a 7.68 would be $76,800 dollars. We believed that it was important to demonstrate that a solar PV system be affordable so we used a more economical 3.6 KW systems. During the competition we found the 3.6 kW systems adequate for our needs if we managed the load and did not utilize every appliance and charge the electric car at the same time. Our load analysis revealed that we needed a capacity of 1,107 Ah (accounting for 3 dark days) to power the system. We installed 20-Trojan L-16 6V batters to meet our storage needs.

Table 2 shows that the energy needs of the house average 10.33 kWh a day, theoretically creating surplus energy that could be used to charge the electric vehicle.

Inverter Powered Appliance	Whrs/day
17" Computer Monitor	300.0
Computer/Web Server	1320.0
19" Television	480.0
Inkjet Printer	17.5
Washer-Dryer	35.7
Dishwasher	1450.0
Cook top	1800.0
Differential Controller	800.0
Slow Pump	850.0
Lighting	1176.0
Ceiling Fans	150.0
Microwave	450.0
Bio Radiant Hydronic System	1500.0
Total	10329

Table 2: Total power requirements

2.5.2 Transportation Analysis

Fig. 7. Ford Electric Think Car adjacent to the UTSOA solar decathlon

The electric car provided to each team for the “Getting Around” competition is a Ford Th!nk Neighbor. The competition organizers recommend that each team charge their car with excess energy generated by their PV system and then analyze how much mileage they will get out of their car. For each full 8-hour charging, the car has a range of 30 miles. The chart below depicts how many miles can be driven per month depending on potential excess power.

Month	Total Power	Excess Power	
	Wh/month	Wh/month	miles/month
January	309802.5	-67.50	
February	424462.5	114592.50	249
March	517072.5	207202.50	450
April	618502.5	308632.50	671
May	615195.0	305325.00	664
June	637245.0	327375.00	712
July	633937.5	324067.50	705
August	609682.5	299812.50	652
September	529200.0	219330.00	477
October	472972.5	163102.50	355
November	406822.5	96952.50	211
December	307597.5	-2272.50	
Total	602492.5	2364052.5	

Table 3: Electric Vehicle Power Consumption

3. CONCLUSION

During the competition the 3.6 kW PV powered solar house provided enough excess power to run the solar electric car 100 miles per week. This distance was adequate to provide for all the grocery shopping and the transportation needs of the home and home office. Although the winning school's 7.68 kW competition entry was able to run their solar electric car 250 miles per week, the UT solar decathlon house easily met the daily supply of energy for its occupants to survive and prosper in today's society and did so at a more affordable PV array size of only 3.6 kW.

4. REFERENCES

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